

Planetary Gamma-ray Spectrometry using a CsI(Tl)-photodiode Array.

R. J. Evans¹, A.R. Martin², T. Carter¹, F Lei¹ and D. Ramsden¹.

¹Physics and Astronomy Department, University of Southampton, Highfield, Southampton, SO17 1BJ, UK.

E-mail: rje@astro.soton.ac.uk.

²AEA Technology plc, Space and Defence Systems Department, F4 Culham, Abingdon, Oxfordshire, OX14 3DB, UK.

Gamma-ray spectrometry is a well established method for the exploration of the surface of solar system planetary bodies which have thin atmospheres. Activation of the surface elements by high-energy particles results in the emission of gamma-rays which carry quantitative and qualitative information about the composition of the upper tens of centimeters of the surface. This technique can be used to study the chemistry of the Moon, Mercury, Mars, comets and the asteroids. In order to fully understand the emergent gamma-ray spectrum, it is important to resolve many of the spectral lines, whilst minimising the effect of the Compton background and escape peak lines. The use of a compact array of CsI(Tl)-photodiode detectors offers significantly better energy resolution than other established scintillator based gamma-ray spectrometers (GRS) (2-3 % at 5 MeV) and offers the prospect of using event-selection techniques such as pair-spectrometry to suppress the Compton continuum and remove the escape peaks. A complex Lunar gamma-ray emission spectrum was derived based on calculations using the Apollo data [1]. A Monte Carlo calculation was then performed to model the response of the CsI(Tl)-photodiode array to this gamma-ray spectrum. The results show that a CsI(Tl)-photodiode array GRS will provide a clearer and thus more easily deconvolved energy-loss spectrum than any other room temperature GRS. This may provide significant advantages for future planetary missions.

Recently, there have been several European spacecraft missions, studied or proposed, that have included a gamma-ray spectrometer in their scientific payload. These include:

- **MORO.** A proposed European Lunar orbiting observatory for the global characterisation of the moons surface.
- **Mercury Orbiter.** A proposed European mission, combining planetary and space physics objectives including the determination of its surface composition by measuring its X- and gamma-ray emission.
- **LEDA.** A candidate for the European Lunar lander mission in Phase 1 of the proposed Moon programme.
- **SMALL.** Has been proposed as a mission to initiate public and political support for Lunar missions in Europe.
- **Rosetta.** A lander rendezvous with a comet to perform scientific experiments on the surface.

The optimum gamma-ray instrument, to provide the highest energy resolution, would normally be a HPGe GRS, cooled to about 100K. However, for certain missions, active cooling systems may be ruled out by the mass or power constraints. The proposed Mercury Orbiter is one such mission [2]. To overcome this problem, consideration must be given to suitable scintillation detectors which have a poorer energy resolution than HPGe but need no cooling. It is in this area

that it is envisaged that CsI(Tl)-photodiode arrays will prove to be a valuable alternative. Other missions where a low power, lightweight, compact and rugged spectrometer would be of value include those of lander modules and surface-roving vehicles.

CsI(Tl)-photodiode arrays of 37 and 96 elements have been successfully tested in laboratory conditions [3][4] leading to the 4096-element array planned for ESA's INTEGRAL mission. The prototype model developed for use in a possible planetary gamma-ray spectrometer consists of 19 elements, hexagonal in cross section, in which each pixel has an across-flats dimension of 2 cm and a length of 5 cm. There are several advantages of using CsI(Tl) arrays compared with a traditional GRS.

- Because of the very small size of the photodiode and pre-amplifier, they form only a small fraction of the overall detector volume. Thus for an equivalent mass, the sensitivity of the CsI(Tl) array will be higher than that for HPGe and NaI(Tl) detectors.
- The ability of the instrument to read out each element in the array both independently and in coincidence with other channels, allows the data to be processed in several ways depending on the energy of the interaction.
- The geometry of a CsI(Tl) array is flexible and may be tailored to make best use of the available mass budget.

The energy resolution of a single element of the 19 element array is shown in Figure 1. At low energies the source of energy broadening is predominantly due to noise from the photodiode and pre-amplifier. At energies of several MeV the energy resolution of the detector is mostly dependent on the light output of the scintillation crystal and the intrinsic broadening. Since CsI(Tl) has a greater light output than most other scintillators and is reasonably well matched to the response of the photodiode the energy resolution for CsI(Tl) is significantly better than that obtained with NaI(Tl) or BGO at room temperature.

The optimum dimensions of the pixels depends on several factors.

- Firstly, for a given mass of scintillator, there will be an optimum depth to achieve the maximum sensitivity for the detection of incident gamma-rays from a planar, isotropic source. This is a balance between the stopping power of the crystal and effective area of the detector. The optimisation for the prototype array was based on a 10 kg detector viewing a planar, isotropic source of 5 MeV photons.
- The energy resolution of the individual elements at several MeV is governed by the light-collection efficiency, which is in turn governed by the length-to-width ratio of the crystals. Thus, for a given length of crystal, there will

be a minimum width for which a good energy resolution can be achieved.

- Coincidence spectrometry requires that the pixelation of the detector should be as fine as possible. However, there is an upper limit to the length-to-width ratio for which a good light collection efficiency can be achieved.

An across-flats dimension of 2 cm was selected for the 5 cm long crystals. It may be noted that improved energy resolution can be achieved if shorter crystals are used. However, this will be at the expense of the sensitivity.

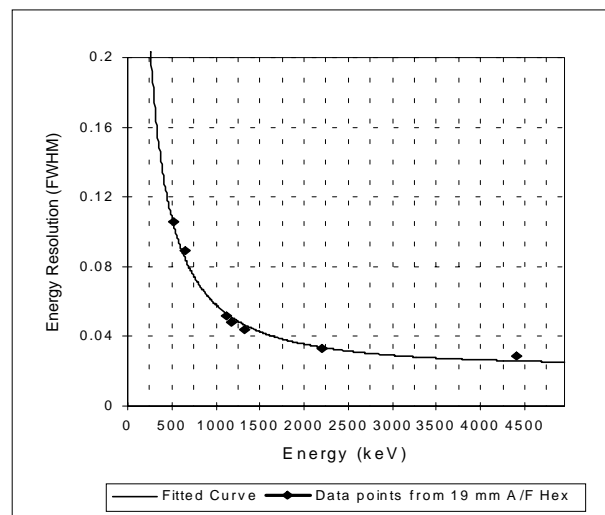


Figure 1. Energy resolution V's Energy for a 19 mm AF by 50 mm long CsI(Tl) element

The gamma-ray spectrum emerging from the lunar surface has been calculated by many people [1], [5], [6] using the data generated during the Apollo missions. The spectrum used as the input to the Monte Carlo model was derived using this work and is shown in Figure 2.

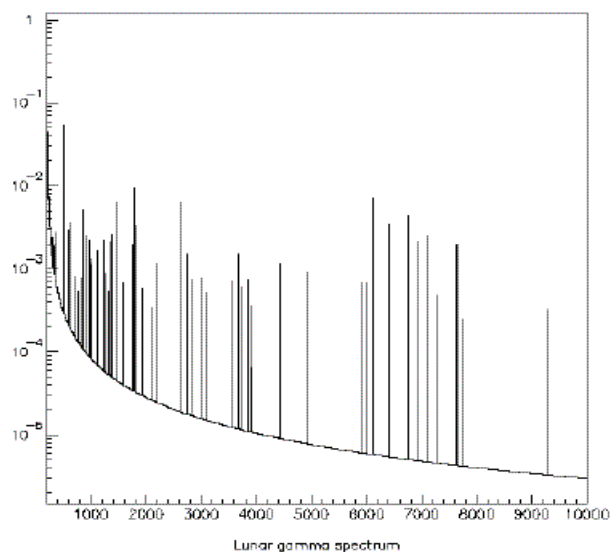


Figure 2. The Derived Lunar Spectrum Used to Determine the Response of the CsI(Tl)-photodiode array

The simulated response of a 10 kg CsI(Tl)-photodiode array, to the complex Lunar emission spectrum is shown in Figure 3. The spectrum shows qualitatively that even from the raw, simple summation spectrum, many features are apparent. When the photon statistics are good it will also be possible to apply event-selection criteria such as pair coincidence spectrometry, greatly reducing the detector-generated Compton continuum, and removing escape peaks. The spectrum then becomes clearer and easier to interpret.

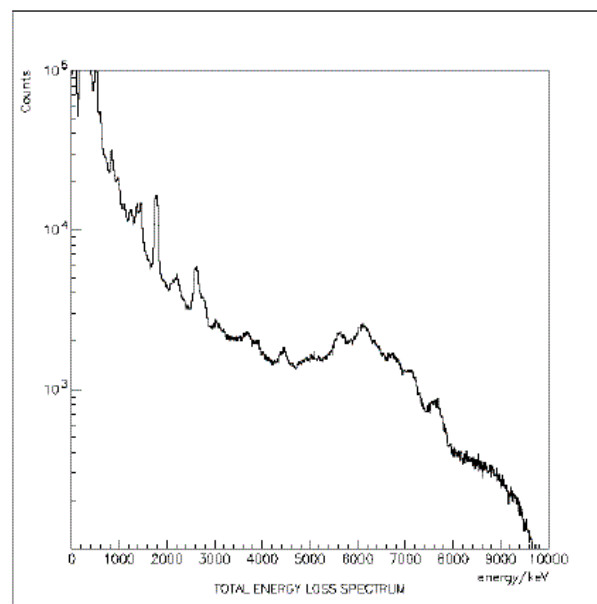


Figure 3. The Simulated Response of a 10 kg CsI(Tl)-photodiode Array to the Complex Lunar Emission Spectrum (Fig. 2.)

These results show that CsI(Tl)-photodiode arrays are a viable option where mission constraints prevent the use of cooled HPGc and can provide a more detailed energy-loss spectrum than any other established room temperature GRS.

References:

1. Reedy, R.C., Planetary gamma-ray spectroscopy. Proc. Lunar Planet. Sci. Conf. 9th, *Geochim. Cosmochim. Acta Suppl.* 10, 2961-2984, 1978.
2. Bruckner, J., Masarik, J., Considerations for gamma-ray spectroscopy of the surface of Mercury., Proc. Lunar Sci. Conf. XXV, 187-188, 1994.
3. Carter T. et al. An imager prototype for gamma-ray astronomy, IEEE conference record, Vol. 1 56-60, 1994.
4. Di Cocco et al., SPIE. X-ray and gamma-ray instrumentation Vol. 1549, 1991.
5. Reedy, R.C., et al., Expected gamma-ray emission spectra from the lunar surface as a function of chemical composition. *J. Geophys. Res.* 78, 5847-5866. 1973.
6. Armstrong, T.W. Calculation of the lunar photon albedo from galactic and solar proton bombardment. *J. Geophys. Res.* 77, 524-536. 1972.